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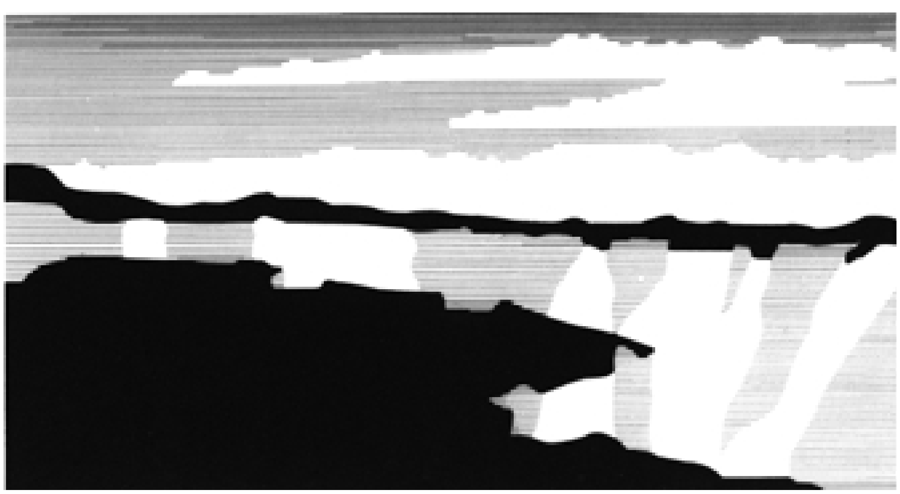

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Comparison of Methodologies for Computing Sky View Factor in Urban Environments

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Introduction

Sky view factor (Ψ_{sky}) is used in radiation balance schemes for the partitioning of longwave and shortwave radiation within urban and forest canopies and complex terrain. In the urban environment, Ψ_{sky} and 1-Ψ_{sky} give a measure of how much radiation will penetrate the canopy and how much will be intercepted by the canopy, respectively. As part of the Oct. 2000 URBAN Field Experiment in Salt Lake City (Shinn et al., 2001), photographs were taken in the downtown area at ground level shooting upwards using a fisheye lens. Utilizing image analysis and in-house processing software, Ψ_{sky} was computed for each photograph. Sky view factor was also computed from 3D building databases using the methodology developed by Ratti and Richens (1999). Although photographic methods for obtaining sky view factor are very accurate, they are time consuming to acquire. Commercial 3D building databases are becoming increasingly more available and sky view factor can be computed from them quite easily. In the future, 3D building datasets might be used to readily compute sky view factor for cities and therefore better estimates of the urban climate could be made. Comparisons of the two methods for computing sky view factor are compared in this paper.

Background

The ratio of the radiation received (or emitted) by a planar surface to the radiation emitted (or received) by the entire hemispheric environment is called the sky view factor Ψ_{sky} (Watson and Johnson, 1987). Ψ_{sky} is determined for a specific point in space, i.e., it gives a measure of the openness of the sky to radiative transport relative to a specific location. Ψ_{sky} varies from zero to one, where $\Psi_{sky} = 0$ means that the sky is completely obstructed by obstacles and all outgoing radiation would be intercepted by the obstacles (such a situation would occur in a tunnel, for example), while $\Psi_{sky} = 1$ means that there are no obstructions and all outgoing radiation would radiate freely to the sky. For the case where buildings cover 50% of the area of the sky, the sky view factor would be greater than 50% because Ψ_{sky} is weighted by the spread of the radiation over the surface of interest. For a flat surface at the ground, the incoming radiation from directly overhead spreads out over a smaller area, while radiation coming from near the horizon would spread out over a very large area, making the effective flux of radiation small.

Sky view factors are often used in canopy radiation budget models in order to simplify the calculations. In ray tracing techniques, trajectories for a very large number of rays originating

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from the point of interest are computed, and their interception by surfaces along with reflections and re-emissions are calculated. The use of sky view factors, although introducing approximations, allows one to characterize the radiation transport between surfaces in an integrated fashion and therefore the number of computations are reduced dramatically. For example, Johnson et al. (1991) derived a formula for the net longwave energy at any surface for a street canyon with uniformly heated street and walls and Ca et al. (1999) and Masson (2000) derived shortwave radiation balance equations. In addition, it has been found that sky view factor correlates well with bulk properties of the urban environment, for example downward longwave radiative flux (Nunez et al., 2001). Furthermore, Oke (1987) found that for calm winds the heat island intensity itself is a function of the sky view factor.

Sky View Factor Calculation from Fish-Eye Photographs

In the Salt Lake City study, a digital camera (Nikon CoolPix 950) with a fish-eye hemispheric lens (Nikon FC-E8) was used to take the in situ observations. The Nikon lens used has a field of view (FOV) of 189° (Grimmond et al., 2001). The images were converted from color to black (ground, buildings, and vegetation) and white (sky) by altering the brightness and contrast of each image using Jasc Software's Paint Shop Pro (Fig. 1). To determine the total Ψ_{sky} at each site the equation of Johnson and Watson (1984) is used:

$$\varphi_{sky} = \frac{1}{2\pi}\sin\frac{\pi}{2n}\sum_{i=1}^{n}\sin\left[\frac{\pi(2i-1)}{2n}\right]\alpha_i$$

where n is the total number of annuli, i is the annulus number and α_i is the total angular extent of sky visible in each annulus. This is done using the Grimmond et al. (2001) FORTRAN program (svf.exe) which automatically detects the resolution of the image taken and allows the user to specify the FOV to be analyzed; i.e. corrections to 180° were included at this stage.

Sky View Factor Calculation from Analysis of 3D Building Datasets

High resolution 3D databases of urban areas are becoming increasingly available at low cost. Ratti and Richens (1999) describe an algorithm for computing sky view factor by repeatedly casting shadows on building datasets. The routine is extremely fast and can process large areas of a city at one time - something impossible with traditional vectorial models. The output is a black and white image which shows the amount of light and shadow for each point in space (pixel). The procedure begins by computing the shadows for a large number of fictitious light sources distributed over the sky. The light sources are distributed non-uniformly, with the density of samples higher at the zenith than at the horizon (the precise distribution is obtained by spreading the samples evenly over a unit circle in the horizontal plane, and then projecting up to a unit hemisphere). Then, the number of times each pixel is in light is tabulated. If 1000 light sources are used, any pixel whose count is 1000 can see all the sky and $\Psi_{sky} = 1$, while a count of 0 means the sky is completely obscured and $\Psi_{sky} = 0$. The technique, which was extensively tested in a number of simplified geometrical arrangements for which mathematical formulas for Ψ_{sky} are available, produces very good results within 1-2% of truth. Sky view factor computations were performed with the Salt Lake City building data using a 2m pixel size.

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In-Situ Photographic Results

Figure 2 shows the computed sky-view value at the approximate location that each street-level photo was taken relative to the building footprints. The majority of photos were taken around the URBAN 2000 tracer release site near 400 S and State Streets and in the most built-up areas along Main St. and 100 S (Brown and Grimmond, 2001). A red color means that Ψ_{sky} is large indicating there are few canopy obstructions, while a purple color means that Ψ_{sky} is small meaning that the canopy is dense and the sky is obscured. Clearly the sky view factor is smallest in narrow alleyways and in regions close to tall buildings. One should also note that many trees were planted along open streets and contributed to reduced sky view factor. The Ψ_{sky} observed in downtown Salt Lake City ranged from 0.33 to 0.90 with an average of 0.70. In a compilation of urban heat island studies, Oke (1981) reported sky view factors for downtown sites ranging from 0.25 to 0.84. Barring et al. (1985) in a study of Malmo, Sweden measured Ψ_{sky} in the center of the city ranging from 0.5 to 1.0. A histogram of the computed sky view factor for downtown Salt Lake City shows that the majority of values fall in the 0.5 to 0.9 range (Fig. 3). A histogram of building heights in the study area shows greater than 90% of the buildings being between 3.5 and 87.5 m and a mode of 10.5-17.5 m. The plan area density λ_P was computed as 0.33, while the frontal area density λ_F varied from 0.25 to 0.36 depending on wind direction. This information might prove useful when comparing our sky view factor measurements to other cities.

3D Building Database Results

Using the 3D Salt Lake City building database, sky view factor was computed on a 2m grid in the downtown area (Fig. 4). It is clear from the figure that Ψ_{sky} is small in the denser, built-up areas and closer to one in open areas. The overall agreement between photographic results and results computed using the 3D building database is very satisfactory, with average values of 0.63 and 0.70 respectively. A point-by-point comparison is shown in Fig. 5. Substantial differences appear at a few locations and can be partially attributed to the nature of the building database used for the simulation. First, the building database used in the computations has a rather coarse resolution (2m/pixel) which generates uncertainty on the building position and on the position of the points where values are being measured. Second, it uses a flat roof approximation, where peaked roofs, roofs with penthouses, and buildings with multiple heights are averaged to one height. An additional source of uncertainty is the absence of trees and other urban furniture in the building dataset. We will investigate in future simulations whether a more refined 3D building database will produce even better agreement between numeric and photographic results.

Summary & Conclusions

Sky view factor was measured in downtown Salt Lake City using fish-eye photographs and a 3D building database. Comparisons of the two methods showed reasonable agreement in the computed sky view factor values, however, some differences were noted. A follow-on study will utilize a more accurate 3D building database to see if agreement improves.

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Figure 1. Fish-eye image before and after being processed.

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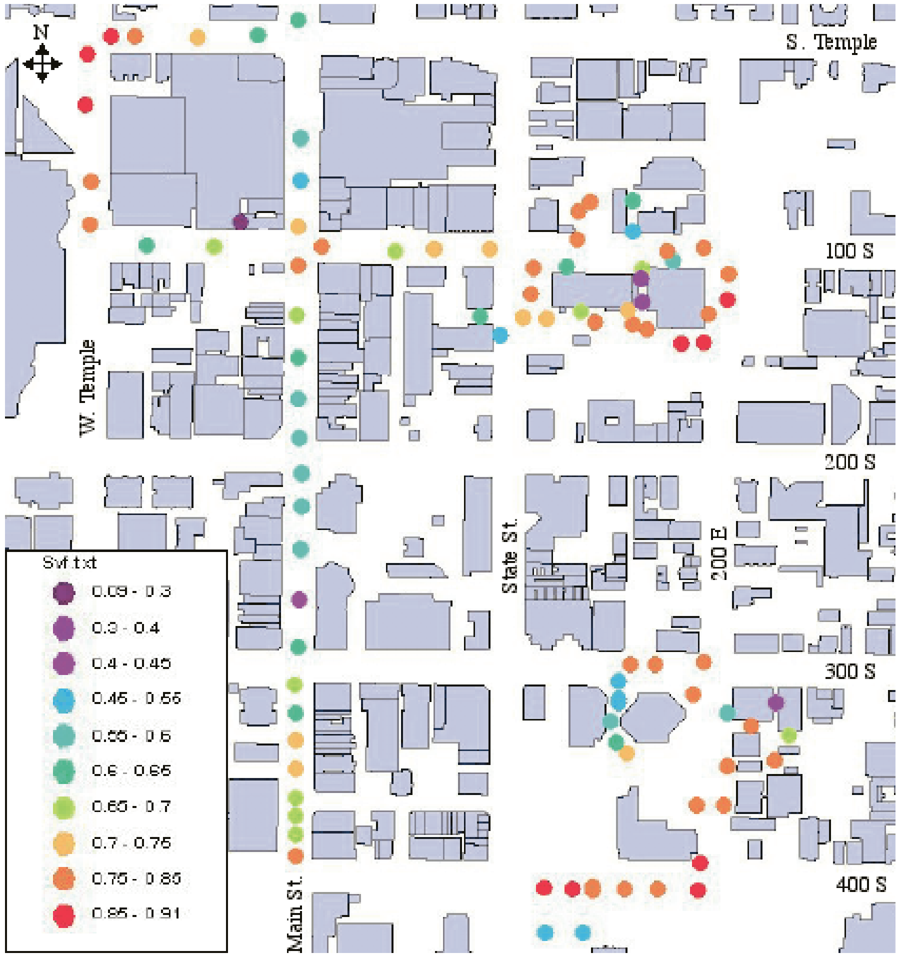

Figure 2. The computed sky view factor overlaid onto downtown Salt Lake City building footprint map. Photos taken Oct. 22, 2000.

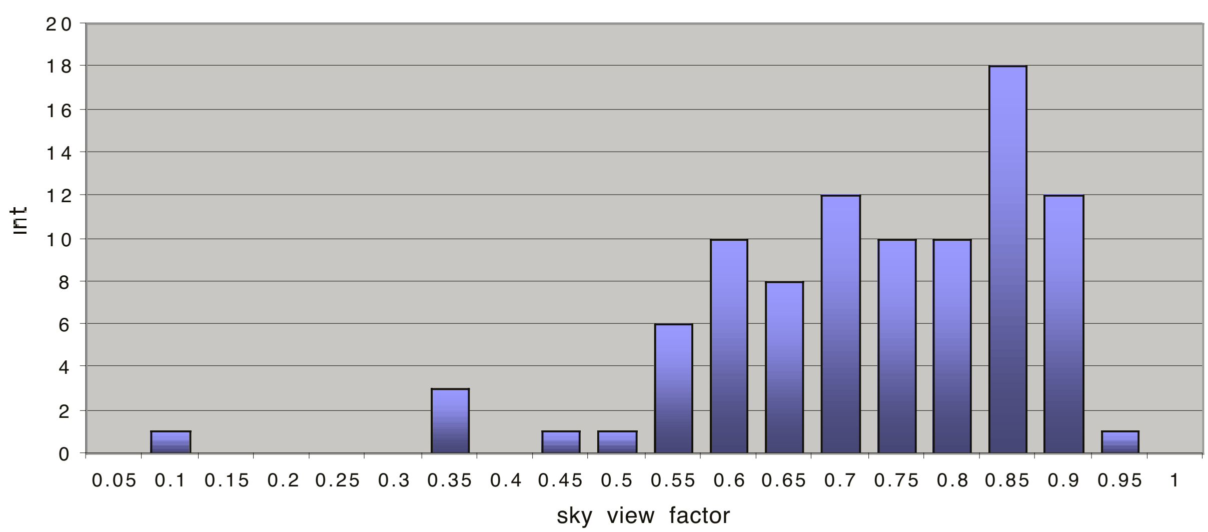

Figure 3. A histogram of the computed sky view factor for street-level positions in downtown Salt Lake City. Photos taken Oct. 22, 2000 and do not include rooftop images.

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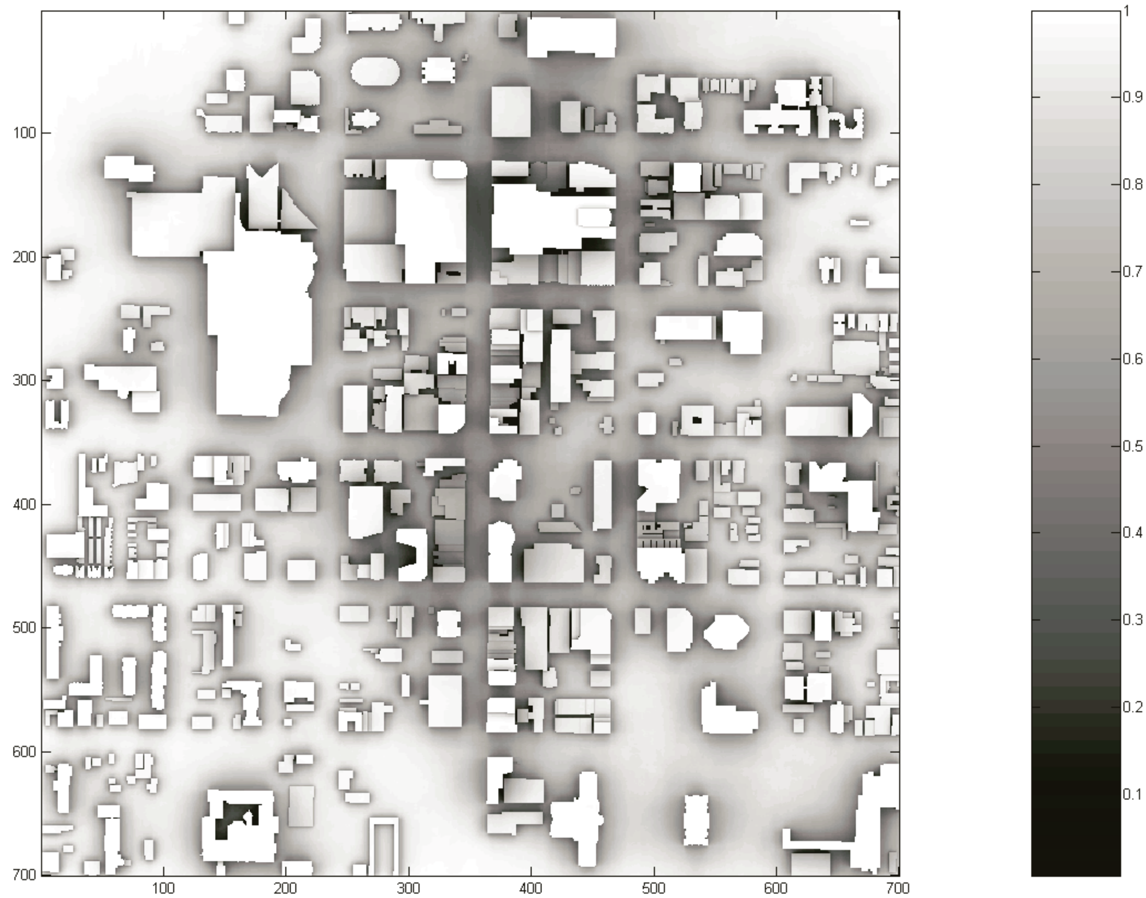

Figure 4. The computed sky view factor using the 3D building database.

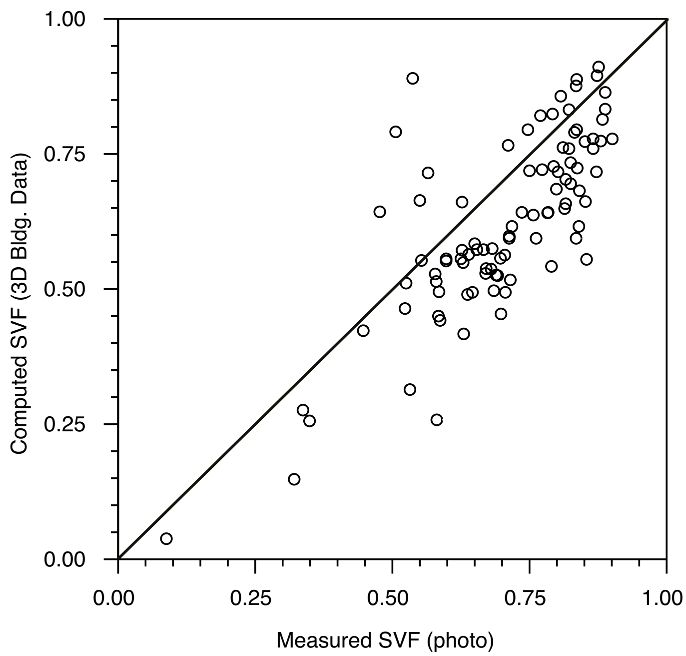

Figure 5. Comparison of the sky view factor computed from fisheye images and the 3D building database.

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